Finite Element Analysis of the main stresses in Gamma Rod Osteosynthesis

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Abstract. The paper presents the results obtained within the Finite Element Analysis of the Gamma rod, used to treat unstable fractures at the intertrohanteric and subtrohanteric level. Trochanteric fractures are a very common type of fracture found worldwide in both young and old people. The paper presents the main stages of the FEA, starting with the creation of the CAD model of the Gamma rod and ending with the Von Mises voltage field, for two of the most used titanium alloys used in the manufacture of rods (Ti-6AI-4V and Ti-6AI-7Nb). Finally, a series of conclusions are presented regarding the advantages of using Gamma rods in treating certain fractures at the trochanteric level.

1. Introduction

Trochanteric fractures are a very common type of fracture found worldwide in both young and old people. These fractures require emergency surgical treatment because patients must be mobilized early, thus reducing the period of postoperative immobilization. Another reason for rapid surgery and careful postoperative care of patients is the avoidance of intraoperative and postoperative complications [1].

The purpose of the Gamma rod is to treat unstable fractures at the intertrohanteric and subtrohanteric levels. This type of rod was developed following studies on corpses in the 80s. Studies show that this type of rod is much more effective than the DHS (Dynamic Hip Screw) method, a method used to treat the same types of fractures, Gamma rod having mechanical strength larger and better weight distribution, being fixed in the middle of the axis of gravity [2].

The Gamma nail involves an intramedullary rod through the end of which enters a nail that is screwed to the level of the femoral head, thus consolidating the head with the rest of the femur. This implant allows the two parts to slide to make an impact [1].

The surgical technique has a number of advantages, with an average duration of 35 minutes, a reduced intraoperative blood loss and reduced tissue damage. The distal screw prevents the rod from rotating and can be inserted without using the imaging method [2].

Over time, however, the Gamma rod has presented many postoperative complications, the most common of which is the femoral shaft fracture caused by the tip of the rod [1].

The main causes of trochanteric fractures: habitual trauma, street trauma, road accidents, industrial traumas [4].

2. Material and Method

Gamma rods are indicated in inverted obliquity trochanteric fractures where they represent the ideal implant. In unstable peritrochanteric fractures, the Gamma system can be used as an alternative to the compression screw [5].

The demands on the femur are: 2460 N on the femoral head, 1700 N on the great trochanter due to the gluteal muscles and 771 N on the small trochanter due to the psoas-iliac muscle [6].

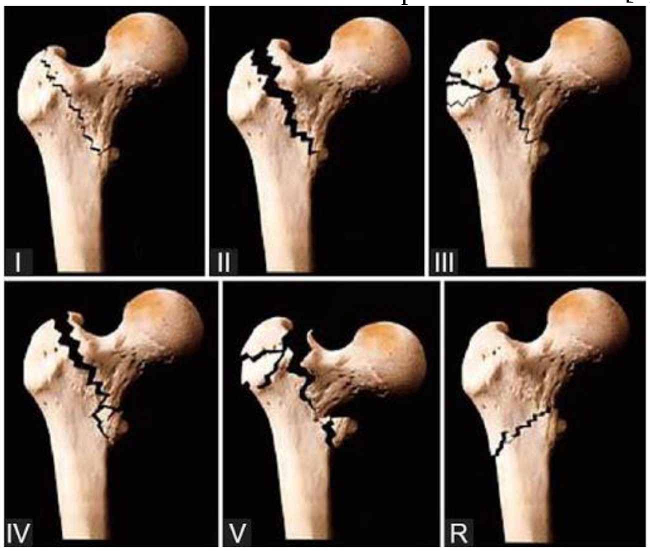


Figure 1. Types of peritrohanteric fractures [9].

2.1. Biomaterials used in the construction of the Gamma rod

The implantable system of the intramedullary short Gamma rod consists of a short rod, also called a nail, having a standard size, one or two nails that are inserted into the head-neck system at the femur. Under the ends of the screws, a plate can be inserted to stabilize the trochanteric mass. On the distal Tuesday of the Gamma rod, another screw is inserted, which has the role of preventing the rotation of the rod [3].

The material from which the short Gamma system for peritrohanteric fractures is made is titanium or titanium alloys [3].

Titanium and its alloys can be processed by advanced powder manufacturing methods, such as additive coating (or 3D printing) or injection molding of metals. This area is receiving increased attention from various production sectors, including the medical devices sector [7].

Titanium is a biomaterial that falls into the category of semi-lightweight materials, with special properties (Table 1). It is completely biocompatible, non-toxic, relatively low density, high specific strength, very good cold and heat resistance, very good fatigue strength, low modulus of elasticity, being compatible with bone structures, not magnetic (Table 1) [4].

Table 1. Properties of titanium

Titanium properties	Stock	Units of measurement
Atomic Mass	49,7	g
Density	4,51	g/cm3
Minimum flow limit	SBO	MPa
Minimum strength of tensile strength	550	MPa

Young module	116	GPa
Poisson coefficient	0,33	
Vicker hardness	970	MPa
Brinell hardness	716	MPa
Melting temperature	1668	° C
Boiling point	3287	°C

By alloying with a number of metals, Al, Mo, V, Mn, Cr, Sn, Fe, Nb, titanium forms various alloys (Table 2). Titanium and titanium alloys are used in a very wide range of medical applications, especially when it comes to dental and orthopedic implants. The conditions of use of titanium and titanium alloys in the medical field are governed by European norms and standard ISO 5832 [4].

Table 2 shows the main categories of titanium and titanium alloys used in medical applications, their characteristics and quality standards. Titanium's corrosion resistance is due to the spontaneous formation of an oxide film on the surface of the material, with a thickness of several tens of nm, which has three main characteristics, extremely useful for medical applications of titanium, namely stability, impermeability, adhesion. [9] Compared to other metallic biomaterials, titanium alloys have significantly higher strength / weight ratios, which is extremely important in the design of orthopedic implants [4].

Table 2. Properties of major titanium alloys

Alloy	Tensile strength (MPa)	Flow limit (MPa)	Elongation (° â)	Modulus of elasticity (GPa)	Standard
Ti-6AI-4V	895-930	825-869	6-10	110-119	IS05832-3
Ti-6AI-7N b	900-1050	880-950	8,1-15	110	IS05832-3
Ti-5AI-2.5Fe	1020	895	15	112	IS05832-3
Ti-6AI-6V-2Sn	965-1103	980	*1k*	110,3	ISO 5832-11
Ti-6AI-6V-2Sn	1280	1210	10	117	ISO 5832-10
Ti-13Nb-13Zr	973-1037	836-908	10-16	77-84	ASTM F1713
Ti-12Mo-6Zr-2Fe	1060-1100	1000	18-22	74-85	ASTM F1813

2.2. *Realization of the CAD model of the Gamma rod*

To create the CAD model, the Catia V5 design software was used, the design process and the final result being presented in Figures 1, 2 and 3.

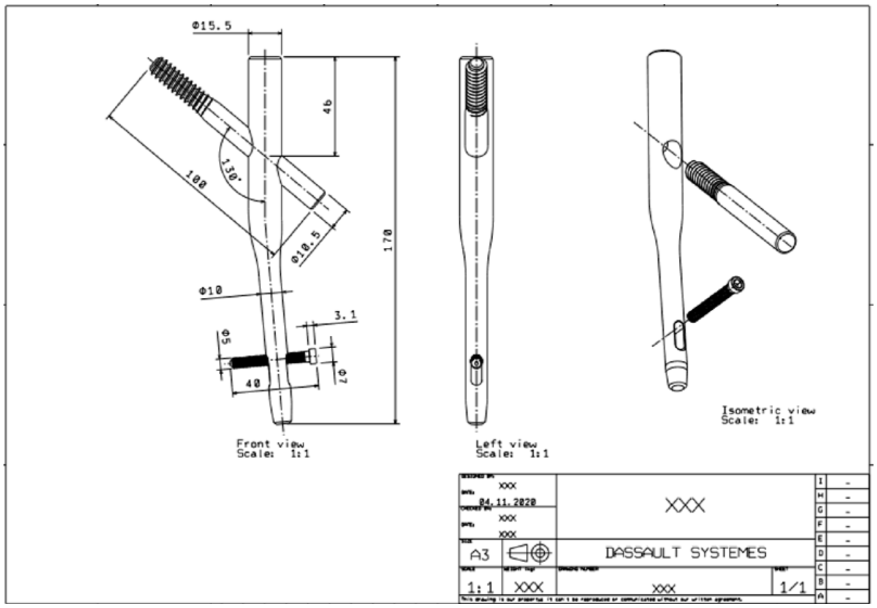
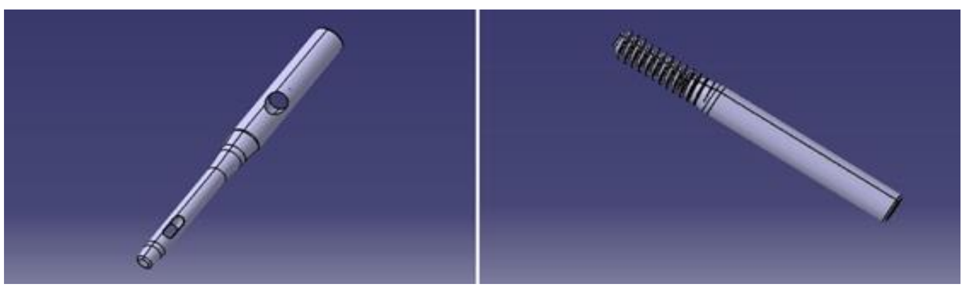


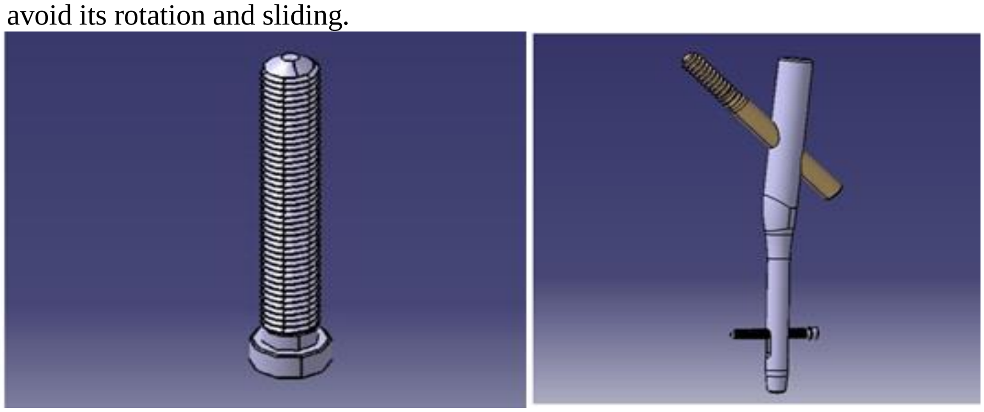
Figure 1. Execution drawing of the implant



a) b)

Figure 2. CAD model of: a) Gamma rod; b) the proximal screw of the Gamma rod

Figure 2 shows the CAD model of the centromedullary rod inserted at the medullary canal of the femur and the CAD model of the proximal screw of the Gamma rod, inserted at the neck and head of the femur to stabilize peritrohanteric fractures, having the role of antirotation of the rod. The distal screw has the role of fixing the rod to avoid its rotation and sliding.



a) b)

Figure 3.a) CAD model of the distal screw of the Gamma rod; b) The assembled CAD model of the Gamma rod

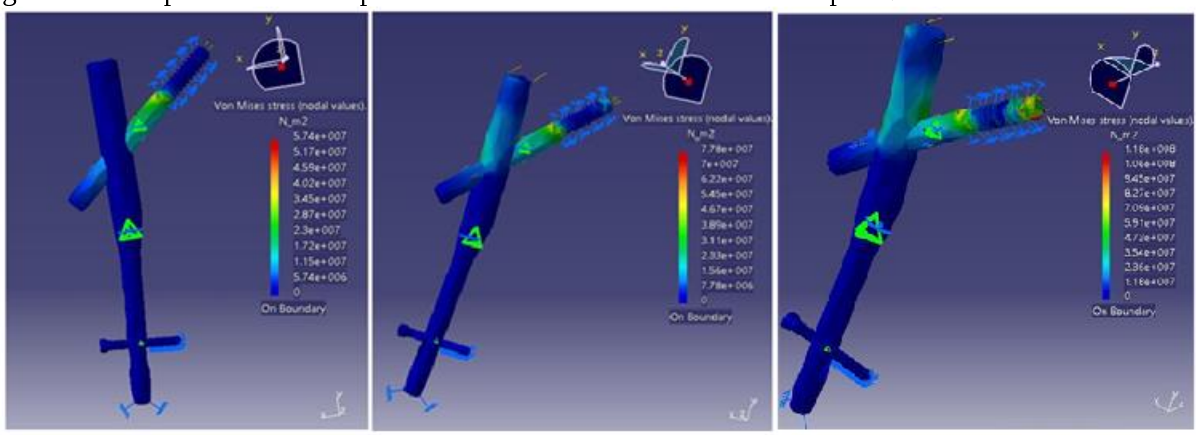
2.3. *Finite element analysis (FEA) of the stresses to which the Gamma rod is subjected*

After making the 3D model of the intramedullary Gamma rod, Finite Element Analysis (FEA) was performed using Catia V5 software, using Titan-based alloys: Ti-6AI-4V and Ti-6AI-7Nb (Table 3) .

Table 3. Properties of alloys used in finite element analysis.

Aloy	Young's module GPa	Poisson's coefficient	Density Kg/m3	Thermal expansion
Ti-6AI-4V	119	0,37	0512	9,1
Ti-6AI-7Nb	110	0,37	0530	9,8

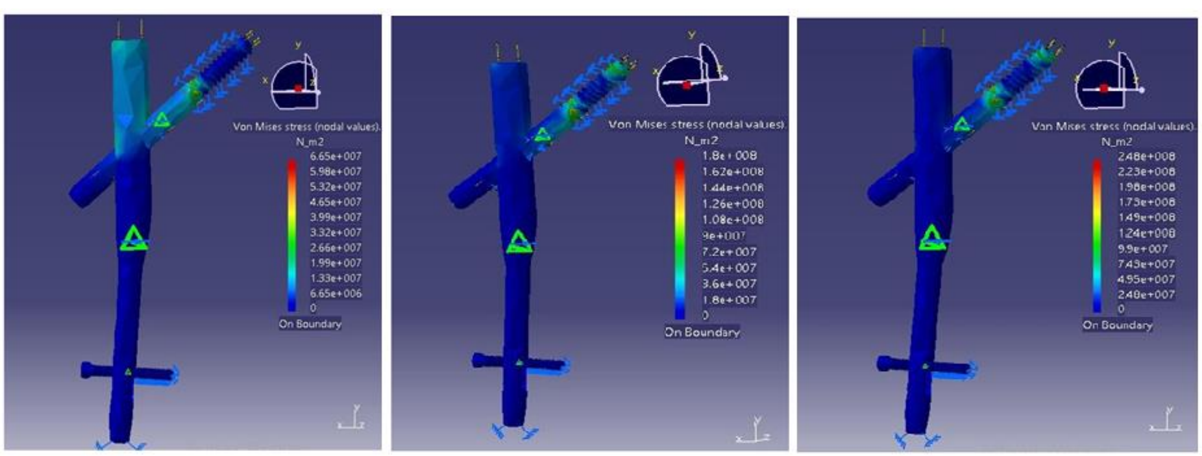
In the Finite Element Analysis, the stress applied to the implant was the compressive force present at the hip joint (which acts on the femoral head and is taken up by the entire femur). The forces exerted by the muscles on the femur were ignored, because they do not act directly on the implant, their influence being insignificant compared to the compression on the femoral head and the implant.



a) b) c)

Figure 4. *Ti-6Al-4V test at: a) 1500 N; b) 2000 N; c) 2500N*

Due to its shape and intramedullary implantation, the Gamma rod takes up this compressive force very well. The force applied to the rod was increased from 1500 N to 2500 N, this being the equivalent of a man of 70 kg and a height of 170 cm (Figures 4 and 5).



a) b) c)

Figure 5. Ti-6Al-7Nb test at: a) 1500 N; b) 2000 N; c) 2500N

3. Conclusions

Following the Finite Element Analysis to which the Gamma rod was subjected, it can be seen that it passed the tests to which it was subjected, resisting the stresses to which it was tested in the case of both titanium alloys. The results obtained for the two alloys are close, but it can be seen that the Ti-6Al-4V alloy recorded lower figures in the simulation.

The forces applied in the tests are similar to those that occur inside the human body, ie compression on the femoral head in bipodal orthostatism. This compression is transmitted further to the femoral shaft, and in the case of osteosynthesis with Gamma nails, it takes over very well the demands on the femur.

Table 4. Finite element analysis results.

Compressive force applied	Ti-6Al-4V alloy		Ti-6Al-7Nb alloy	
	MAX N/	MIN N/	MAX N/	MIN N/
1500N	5,74*	5,74*	6,65*	6,65*
2000N	7,78*	7,78*	1,8*	1,8*
2500N	1,18*	1,18*	2,48*	2,48*

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